BIAS INTRODUCED BY ANEMOMETER STARTING SPEEDS IN CLIMATOLOGICAL WIND ROSE SUMMARIES

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ABSTRACT

Climatological wind rose summaries for pairs of U.S. Weather Bureau Airport Stations, Winston-Salem vs. Greensboro, N.C., and Bakersfield vs. Fresno, Calif., were investigated for differences in the annual percentage frequency of hourly surface wind observations reported as calm; each pair was comprised of stations located close together in the same climatic regions.

Discrepancy in the frequency of calms reported at the paired stations is apparently related to differences in anemometer starting speeds.

Investigation of climatological wind rose summaries for 30 additional U.S. Weather Bureau Airport Stations disclosed an apparent bias in the frequency of reported calm conditions.

1. INTRODUCTION

A climatological study of hourly surface wind speeds by Holzworth [1] revealed that all except two of 16 U.S. Weather Bureau Airport Stations investigated over a period of 2 yr., 1962 to 1963, displayed relatively high frequencies of calm, zero frequencies of 1-kt. speeds, and relatively low frequencies of 2-kt. speeds. Of the two stations, Washington, D.C., was the only station that reported more than a few 1-kt. speeds. Investigation of this anomaly disclosed that for 18 of 24 mo. of data recorded at Washington, D.C., an Automatic Meteorological Observing Station (AMOS) was in operation, and this equipment was known to be capable of detecting 1- and 2-kt. winds. Holzworth concluded that the bias toward calm at 15 of 16 stations was due to the lack of anemometer response at speeds less than about 3 kt.

The purpose of this study is to determine whether the bias noted by Holzworth is apparent in any of the long-term climatological wind rose summaries (5- and 10-yr.) published as part of the Decennial Census of the United States Climate by the Weather Bureau [2]. Moreover, variations of anemometer type from station to station are investigated to reveal any influence of different starting speeds on climatological wind rose summaries.

2. DATA AND TABULATIONS

In the wind rose summaries produced for the Decennial Census, wind speeds (m.p.h.) are grouped as follows: 0 to 3, 4 to 7, 8 to 12, 13 to 18, 19 to 24, 25 to 31, 32 to 38, 39 to 46, and 47 and over. Percentage frequency of calm is listed separately as well as included in the 0 to 3 group. Tables 1 and 2 are examples.

Since this study is concerned with the erroneous classification of speeds of 1, 2, or 3 m.p.h. as calm, all pertinent data are contained in the percentage frequencies listed as calm or in the 0- to 3-m.p.h. speed group. If the starting speed of a specific type of anemometer causes a bias by classifying light winds as calm, comparison of the wind rose summary with that of another station equipped with a different type of anemometer should disclose differences in the proportion of percentage frequencies of calm to percentage frequencies in the 0- to 3-m.p.h. speed group. The stations should be close enough to share the same climatic regime, and no major topographic features should intervene.

Evidence of this type of bias was revealed by two wind rose summaries obtained for an air pollution study in North Carolina. When summaries were compared for two nearby sites, WBAS Greensboro (Greensboro-High Point Airport and WBAS Winston-Salem (Smith Reynolds

TABLE 1.—*Percentage frequencies of wind direction and speed*

[Hourly observations of windspeed (m.p.h.)]

Direction	0–3	4–7	8–12	13–18	19–24	25–31	32–38	39–46	47–over	Total	Av. speed
Greensboro, N.C., Greensboro-High Point AP—Annual 87,672 obs.											
N	0.9	1.7	1.7	0.7	0.1	+	+			5.1	8.1
NNE	.7	1.7	2.0	.9	.1	+	+			5.5	8.7
NE	1.2	2.9	4.0	2.6	.5	0.1	+	+		11.2	9.8
ENE	.9	2.1	2.6	1.3	.2	+	+			7.1	9.1
E	.7	1.1	.7	.2	+	+				2.7	6.5
ESE	.4	.6	.4	.1	+	+				1.5	6.5
SE	.6	.8	.6	.1	+					2.1	6.1
SSE	.5	.8	.4	.1	+					1.8	6.1
S	1.1	2.1	1.3	.3	+	+	+			4.8	6.6
SSW	1.5	3.6	2.8	.9	.1	+	+			8.9	7.5
SW	2.6	6.3	5.7	2.4	.3	.1	+			17.4	8.1
WSW	1.1	2.5	2.5	1.0	.1	+				7.1	8.1
W	1.1	1.8	1.4	.5	.1	+	+			4.8	7.3
WNW	.6	1.2	1.3	.9	.2	+	+			4.2	9.5
NW	.7	1.4	2.1	1.6	.4	.1	+	+		6.3	10.5
NNW	.6	1.2	1.6	1.0	.2	+	+		+	4.5	9.7
CALM	5.0									5.0	
Total	20.2	31.7	30.9	14.4	2.4	.4	+	+	+	100.0	8.0
Winston-Salem, N.C., Smith Reynolds AP—Annual 43,848 obs.											
N	.2	.9	1.1	.4	+	+	+			2.7	8.9
NNE	.2	1.4	2.7	2.2	.4	.2	+	+		7.1	11.9
NE	.3	1.6	3.5	3.6	.9	.4	0.1	+		10.3	12.9
ENE	.2	1.3	1.9	1.1	.1	+	+	+		4.7	10.0
E	.3	.9	.7	.2	+	+	+			2.1	7.7
ESE	.2	.6	.4	.1	+		+			1.3	7.2
SE	.3	1.0	.6	.2	+	+	+			2.1	7.5
SSE	.2	1.1	1.2	.5	.1	+	+			3.1	9.0
S	.2	1.0	1.5	.9	.1	+	+			3.7	10.2
SSW	.2	1.6	3.9	2.7	.3	.1	+			8.9	11.2
SW	.3	2.5	4.5	2.3	.3	.1	+			10.1	10.1
WSW	.3	2.0	3.2	1.6	.2	+	+			7.4	9.9
W	.2	1.2	1.5	.9	.2	.1	+			4.0	10.2
WNW	.3	1.6	2.0	1.6	.4	.2	+			6.1	11.3
NW	.3	1.8	2.8	1.8	.6	.2	+			7.5	11.1
NNW	.2	1.1	1.4	.8	.2	+				3.7	10.1
CALM	15.1									15.1	
Total	19.0	21.7	33.0	20.6	3.9	1.4	.3	0.1		100.0	9.0

[1] National Center for Air Pollution Control, Public Health Service, U.S. Department of Health, Education, and Welfare.

TABLE 2.—*Percentage frequencies of wind direction and speed*

[Hourly observations of windspeed (m.p.h.)]

Direction	0–3	4–7	8–12	13–18	19–24	25–31	32–38	39–46	47–over	Total	Av. speed
Fresno, Calif., Fresno Air Terminal—Annual 87,672 obs.											
N	1.9	1.7	0.3	+	+					3.8	4.4
NNE	.9	.6	.1	+	+	+				1.7	4.1
NE	2.2	1.5	.1	+	+					3.8	4.0
ENE	1.6	1.8	.2	+	+					3.6	4.5
E	2.4	3.0	.4	+						5.8	4.6
ESE	1.3	2.4	.7	0.2	+					4.6	5.7
SE	1.9	3.2	1.6	.5	+	+				7.2	6.5
SSE	1.0	1.8	.9	.2	+	+	+			4.0	6.3
S	1.3	2.1	.7	.2	+	+				4.3	5.7
SSW	1.0	1.3	.4	.1	+					2.8	5.1
SW	1.7	1.9	.4	.1	+	+				4.1	4.7
WSW	.8	1.4	.5	+	+					2.8	5.5
W	1.5	2.8	1.6	.3	+	+				6.2	6.3
WNW	1.5	5.0	5.9	1.9	0.1	+				14.3	8.3
NW	2.9	8.0	7.0	3.0	.3	+	+			21.1	8.1
NNW	1.9	2.8	1.0	.2	+					6.1	5.7
CALM	3.9									3.9	-------
Total-----	29.8	41.2	21.6	6.8	.5	+	+			100.0	6.1
Bakersfield, Calif., Meadows Field—Annual 43,848 obs.											
N	.1	2.2	2.7	1.0	.1	+				6.2	9.1
NNE	.1	1.3	1.0	.2	+					2.6	7.8
NE	.1	2.3	.6	+	+	+				3.0	6.3
ENE	.2	3.9	1.3	+	+					5.4	6.5
E	.2	3.0	.7	.1	+					4.0	6.2
ESE	.2	2.0	.5	.1	.1	.1				2.9	7.5
SE	.2	1.4	.4	.2	.1	+	+			2.3	7.4
SSE	.1	.6	.2	.1	+	+	+			1.1	8.0
S	.1	.8	.2	+	+					1.1	6.2
SSW	.1	.6	.1	+		+				.8	5.9
SW	.1	1.3	.4	+	+					1.9	6.5
WSW	.1	1.3	.8	.1	+	+				2.3	7.1
W	.1	1.8	1.5	.3	+	+				3.7	7.9
WNW	.2	2.6	4.2	2.4	.2	+	+			9.6	10.1
NW	.2	3.0	5.6	3.3	.3	+	+			12.3	10.4
NNW	.1	2.1	3.7	2.1	.3	.1	+			8.3	10.4
CALM	32.6									32.6	-------
Total-----	34.7	30.0	23.7	10.1	1.1	.3	+			100.0	5.8

Airport), a significant difference was observed in the percentage frequencies of the 0- to 3-m.p.h. speed group, although the distance between the sites was only 18 mi. and the intervening terrain mostly low and rolling.

In table 1 both stations show almost the same total percentage in the 0- to 3-m.p.h. speed group, 20.2 and 19.0, but Greensboro recorded only 5.0 percent calms, whereas Winston-Salem recorded 15.1 percent. The effect of the higher frequency of calms at Winston-Salem is observed in the column headed 0–3 in table 1. Directional percentages in the column vary from 0.2 to 0.3 at Winston-Salem, whereas at Greensboro the variation is from 0.4 to 2.6 percent. Apparently certain winds reported as calm at Winston-Salem were reported as light winds in the 1- to 3-m.p.h. category at Greensboro. Since a classification of calm does not provide a directional component for the observation, a persistent bias toward reporting low speeds as calm will distort a wind rose summary in two ways: 1) directional variations in the 1- to 3-m.p.h. speed group will be minimized; 2) average speeds computed for each direction will be higher, since low speeds classed as calm cannot be considered in directional speed averaging.

Table 2 illustrates another instance of dissimilar low wind speed frequencies appearing in wind rose summaries computed for nearby weather reporting sites. The two sites at WBAS Fresno (Fresno Air Terminal) and WBAS Bakersfield (Meadows Field), Calif. Although the sites are about 100 mi. apart, wind roses prepared for each site should not be markedly dissimilar, since both are located in the San Joaquin Valley of California with no major intervening terrain features. A study of the calm and low speed percentages in table 2, however, indicates that Bakersfield recorded 32.6 percent of all hourly wind observations as calm whereas Fresno recorded only 3.9 percent. As in the table 1 comparison for Winston-Salem and Greensboro, this disparity distorts the wind rose summary in table 2. Fresno shows directional variation in the lowest speed group whereas Bakersfield does not, and the average speeds for each direction are considerably lower at Fresno.

Inspection of total percentages of the 4- to 7-m.p.h. speed groups of tables 1 and 2 shows 10 percent less occurrences at Winston-Salem and Bakersfield, leading to the suspicion that some 4-m.p.h. winds were reported as calms at these stations. Although directional variations are present, it is difficult to explain a difference of 10 percent when the total percentages of the higher speed groups are much closer.

3. DISCUSSION

Tables 1 and 2 were published as part of the Decennial Census of United States Climate—Summary of Hourly Observations for the years 1951 to 1960 (Greensboro and Fresno) and 1956 to 1960 (Winston-Salem and Bakersfield). These 5- and 10-yr. summaries were produced for most first order U.S. Weather Bureau Stations, and the data summarized would necessarily reflect the characteristics of the instrumentation used during these years. To determine this, we acquired the WBAN-10D forms prepared at each station and inspected them to ascertain the types of wind instruments, height of the anemometers, exposures, and date of installation. Inspection revealed that Greensboro and Fresno were equipped with two wind instrument types, F420 and F102. Winston-Salem and Bakersfield had only F420 instruments.

All U.S. Weather Bureau Airport Stations are supplied with wind equipment of the F420 A, B, C, or D series. This series incorporates a 3-cup rotor-driven d.c. generator to measure speed and a spread-tail vane to sense direction. Wind data are read directly from two indicator dials installed in an instrument panel cabinet or console remote from the anemometer. To give dependability and long service, the bearing and shaft supporting the cup rotor are larger than those usually used with other anemometers. For this reason, and because the generator causes some brush friction and magnetic drag, the starting speed is considered to be from 2 to 3 kt. at ordinary temperatures [3]. Therefore, this instrument alone is unable to fulfill the Circular N [4] criterion for calm defined as winds less than 1 m.p.h. or 1 kt. Indeed, the instrument would indicate winds of 1 and 2 m.p.h. as calm.

Some U.S. Weather Bureau Airport Stations are equipped with an additional instrument, usually an F102, F103, or F104 anemometer. All are 3-cup rotor types with a lower starting speed than the F420 series, since they incorporate a contact-closing mechanism and lack the brush friction and magnetic drag of generator anemometers. Cup rotation equivalent to a specified passage of wind closes an electric contact, which causes a pen deflection at a remote autographic recorder where data from a tipping bucket raingage and a sunshine switch are also displayed on the same chart roll.

If the bias toward calm observed at Winston-Salem and Bakersfield resulted from the lack of an anemometer with a starting speed lower than that of the F420, then inspection of climatological wind roses in the Decennial Census computed for other U.S. Weather Bureau Airport Stations with similar wind instrumentation should show a comparable bias towards high frequencies of calms. To test this hypothesis, we inspected the file of Decennial Census publications at ARFRO, Cincinnati, and, to emphasize the low speed frequencies, considered only stations whose frequency of winds 3 m.p.h. or less was more than 15 percent of total annual occurrences. Of 110 station summaries available, 34 met this criterion. The results are presented in table 3. Of 17 stations with only F420 anemometers, 11 reported occurrences of calms that made up more than 50 percent of frequencies in the 0- to 3-m.p.h. speed group. Of 17 stations equipped with both the F420 and a contact-type anemometer only two reported a frequency of calms greater than 50 percent.

Under average stability conditions wind speed increases with height above the ground at approximately a 1/7th power law, i.e.,

$$\bar{u}_2=\bar{u}_1\left(\frac{z_2}{z_1}\right)^{1/7}$$

where u_2 is the mean wind speed at height z_2, $\bar{u}_1$, the mean speed at height z_1. It might be expected that over 5 or 10 yr. of hourly observations, the highest anemometers would record a lower frequency of calms. Table 3 shows that this is not entirely true. Indeed, the anemometer at Bakersfield was situated at 60 ft., and the one at Fresno at 42 ft.; yet at Bakersfield 93.9 percent of occurrences in the 0- to 3-m.p.h. speed group were calms, and at Fresno, 13.1 percent. Also, the sensor at Winston-Salem was located at 63 ft. and at Greensboro, 56 ft.; but again the percentage of calms was greater with the higher anemometer. Apparently, the advantage of greater height was not sufficient to override the lower starting speeds of the supplementary contact-type anemometer.

TABLE 3.—*Decennial census of United States climate, total annual hourly observations, percentage frequencies*

U.S. Weather Bureau Airport Stations	Calm	0–3 m.p.h.	Calm/0–3 (%)	Anemometer Heights (ft.)
Group I—Stations With Only F420 Anemometer				
Augusta, Ga.	7.2	35.5	20.3	25
Bakersfield, Calif.	32.6	34.7	93.9	60
Baton Rouge, La.	11.5	17.4	66.1	20
Burbank, Calif.	17.0	52.0	32.7	89
Charleston, W. Va.	16.0	28.8	55.6	32
Columbia, S.C.	14.4	24.8	58.1	36
Lake Charles, La.	12.0	19.0	63.2	39
Las Vegas, Nev.	15.6	18.4	84.8	20
Medford, Oreg.	31.3	47.3	83.1	20
Montgomery, Ala.	8.4	30.7	27.4	22
New Orleans, La.	12.0	16.0	75.0	20
Oakland, Calif.	15.6	25.8	60.5	49
Phoenix, Ariz.	14.3	38.4	37.2	41
Raleigh, N.C.	11.2	18.0	62.2	26
Reno, Nev.	20.6	51.7	39.8	20
Wilmington, Del.	6.5	15.1	43.0	20
Winston-Salem, N.C.	15.1	19.0	79.5	63
Average	15.9	29.0	57.8	35
Group II—Stations with F420 and Supplementary Anemometer				
Birmingham, Ala.	14.4	27.3	52.7	63
Charlotte, N.C.	4.7	20.1	23.4	85
Chattanooga, Tenn.	23.4	38.9	60.2	54
Columbus, Ohio	7.0	25.8	27.1	20
Evansville, Ill.	8.0	18.8	42.6	64
Fresno, Calif.	3.9	29.8	13.1	42
Greensboro, N.C.	5.0	20.2	24.8	56
Harrisburg, Pa.	7.5	28.2	26.6	46
Jackson, Miss.	7.7	33.1	23.3	30
Knoxville, Tenn.	10.7	28.6	37.4	73
Los Angeles Int. AP, Calif.	13.0	28.0	46.4	20
Madison, Wis.	5.6	15.2	36.8	21
Nashville, Tenn.	7.8	27.2	28.7	42
Portland, Oreg.	11.0	28.0	39.3	33
Rapid City, S. Dak.	5.2	15.0	34.7	32
San Antonio, Tex.	3.0	18.0	16.7	31
San Diego, Calif.	6.0	28.0	21.4	60
Average	8.5	25.3	32.7	45

Since 1961, the last year included in the Decennial Census, there has been an effort to move anemometers away from airport buildings and roof locations and place them near the runway complex at heights no more than 30 ft. or less than 15 ft. above the nearest primary runway. Unfortunately, wind data included in the Decennial Census and other climatological studies before 1961 were produced without advantage of a standardized anemometer height.

4. CONCLUSIONS

A bias toward calms in a climatological wind rose summary may be suspected if the summary shows little or no variation of directional percentage frequencies within the 0- to 3-m.p.h. speed group. If this condition exists, then average speeds computed for each direction will be erroneously high because light winds are not included in the averaging computation. This bias results from the use of anemometers with starting speeds of 2 to 3 m.p.h., a characteristic inherent in the F420 generator-type anemometer. Stations equipped with both a contact-type anemometer as well as a standard generator-type anemometer will effectively remove the bias.

Annual wind rose summaries produced as part of the Decennial Census of the United States Climate indicate a bias toward calm for U.S. Weather Bureau Airport Stations equipped with only an F420 generator-type anemometer. If 15 percent or more of annual hourly observations in a climatological wind rose fall in the 0- to 3-m.p.h. speed group, directional variations should be checked for bias; if bias is suspected, investigators should check the type of wind equipment in use during data collection to determine anemometer starting speed.

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PICTURE OF THE MONTH

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A weak low pressure area located in New Mexico on March 9 moved eastward and rapidly intensified over Louisiana. By 1500 GMT March 12, the storm was centered in Tennessee with precipitation occurring from Louisiana northeastward to Maine. This ESSA-3 photograph (fig. 1), taken at 1653 GMT, shows the large area of cloudiness associated with the storm.

To produce the picture in figure 2, the analog signals of the original photographs of figure 1 were digitized and rectified to a polar sterographic projection by means of a

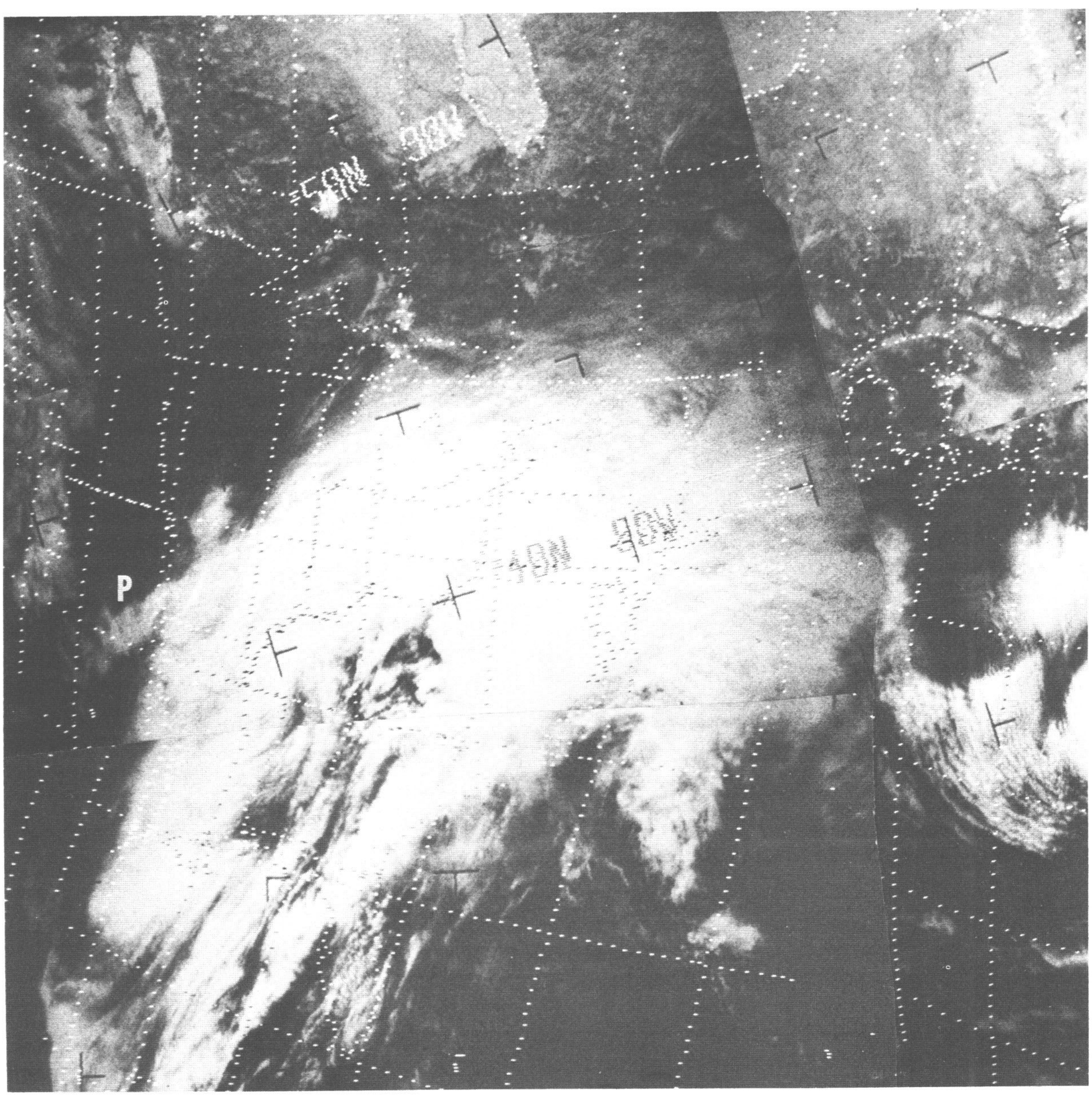

FIGURE 1.—ESSA-3, pass 6631-2, 1653 GMT, March 12, 1968.

computer. The brightest part of the signal was color reversed to black; the remainder of the brightness responses were not reversed. This computer processed mosiac was then run off on a facsimile recorder. The result was photographed to produce figure 2. (Rectangular dark area to upper left represents a data gap.)

Of particular interest is the relationship between the brightest clouds and the precipitation pattern of the storm. Precipitation amounts for the 6-hr. period ending at 0000 GMT March 13 are shown in figure 3. The dotted line represents the smoothed edge of the dark clouds in figure 2. These clouds closely outline the area of precipitation. Discrepancies between the precipitation area, e.g. over Florida, and the cloud area are accounted for by the difference between picture time and the time period of the precipitation record.

Snow left in the wake of the storm can be seen at P. Since this area is not as bright as the clouds, the feature remains the same in both figures.

The process of color-reversing, or otherwise enhancing cloud photographs, can be used to facilitate interpretation and to extract more detailed information from satellite photographs.

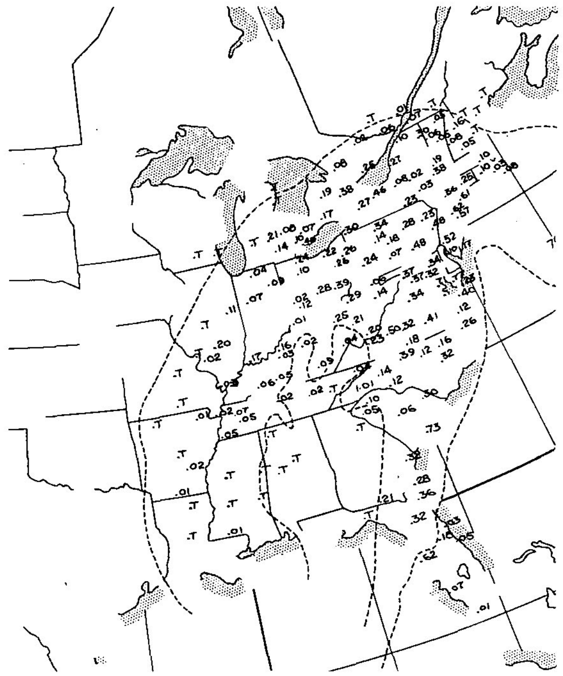

FIGURE 3.—Six-hr. precipitation map, 0000 GMT, March 13, 1968.

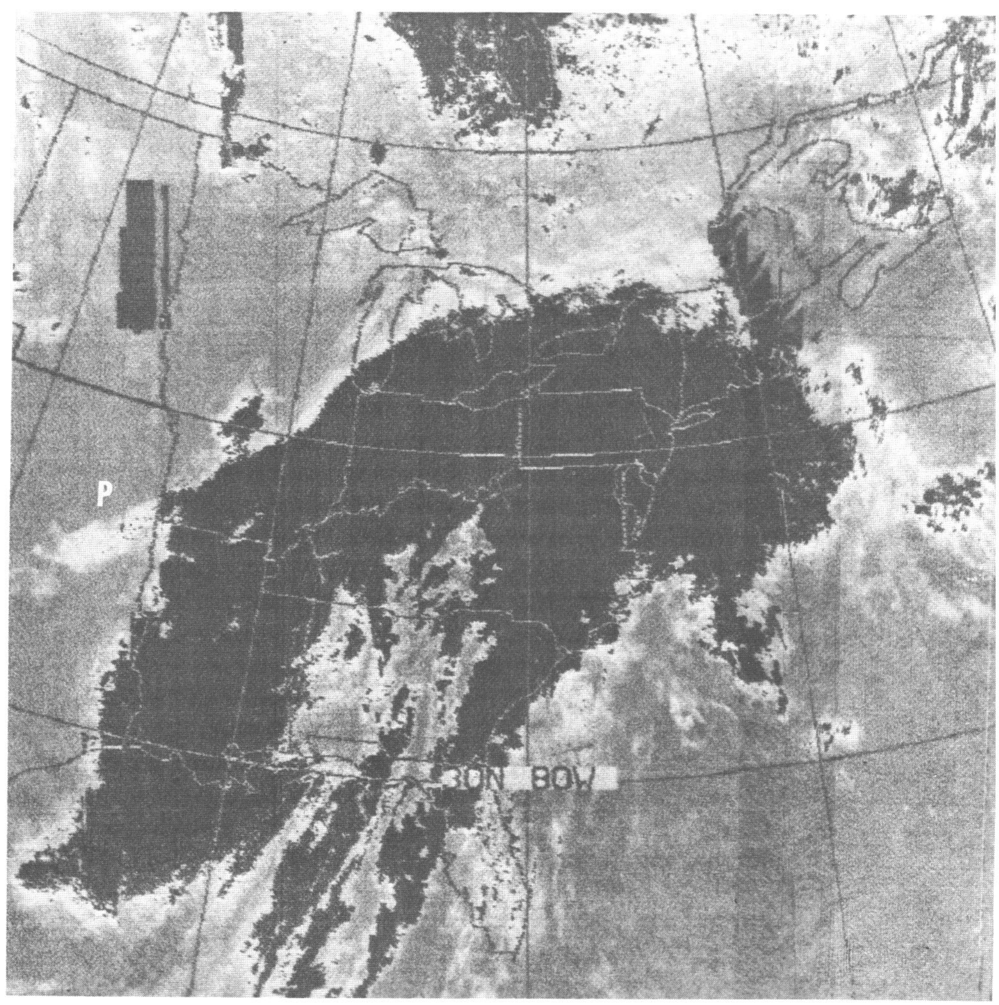

FIGURE 2.—Digitized photograph of figure 1.